

APPENDIX B

KEY PARAMETERS OF THE EPIDEMIOLOGICAL MODEL

The key disease parameters for the model are:

- *Incubation and latent period.* The incubation period for FMD has been found to be 4 to 14 days between farms; virus excretion will commence 1 to 5 days before the appearance of lesions (Garner and Lack, 1995). Since the model uses half week periods, it is assumed that any herd coming into contact with the virus will be latent for one period and infectious the following period.
- *Infectious period.* The infectious period has been found to be correlated with type and herd size, husbandry practices, and whether the disease is allowed to run its course, or whether controls are applied lesions (Garner, 1992; Donaldson, 1994a; Sanson, 1994; Sellers and Daggupati, 1990; Willeberg et al., 1994). If depopulation is not applied, the infectious period for cattle can last between one and nine weeks; for pigs, between 10 to 17 days. If depopulation is applied on the same day the disease is diagnosed or the next, the infectious period can be expected to last four days.
- *Immune period.* If stamping-out is the policy to be applied, the immune period is not important. All infected animals become immune one to two weeks after being infected. If vaccination is applied, herd immunity decreases slowly through births and replacements.
- *Dissemination rate.* The dissemination rate represents the average number of farms per time period to which the virus is transmitted by one affected farm, regardless of the state of the farm receiving the virus—the contact being sufficiently close that disease transmission can occur. Whether the virus results in a new infection depends on the state of each receiving farm. Contact is used in its broadest sense and applies to all routes through which the virus can be transmitted from one herd to another. The dissemination rate depends on environmental factors (landscape, herd density, weather, etc.), type of farming (intensive production, husbandry, fomite opportunities), animal movements (marketing, pasture seekings), farmer behavior (movements, prevention measures), and the control strategy (stamp-out, vaccination).

A hog producer in the South Valley known for his deficient bio-security practices was selected as the index farm for the construction of the epidemiological model. Twenty dairies and hog operations were identified in a three mile radius circle centered on the index farm, and 40 facilities were located within five miles of it. Feedlots were not included in the count due to a lack of geographical information.

Considering that the climatic conditions permit airborne diffusion almost every day of the year, and that the virus is carried in puffs by the wind, it was estimated that large dairies and feedlots would have six effective contacts per week due to airborne diffusion, small dairies would have four effective contacts, large pig operations would have ten, and backyard operations would have one. This number of contacts is maintained until the premises are depopulated. This is probably an underestimation of the true number of contacts since the massive amounts of virus excreted by the large herds in the South Valley would have the potential to infect beyond five miles. Determination of the real importance of airborne diffusion is beyond the scope of this study. However, due to the importance of the issue, it should be researched further.

Movements of animals, people and equipment out of premises with susceptible animals in the South Valley, analyzed in Chapter 4, suggest that the dissemination rates used in previous studies do not reflect the intense production conditions of the South Valley. The number of effective contacts due to all other factors except weather in the first two weeks of the outbreak was estimated to be 10 per week for large dairies, four for feedlots, six for small dairies, six for large pig operations, and zero for backyard operations. This latter figure reflects the fact that these producers have very little contact with commercial channels so it is assumed that the disease spreads from the index farm by air. For comparison, dissemination rates at the start of an epidemic used in European studies range from 2.5 to 4.5 herds per week (Dijkhuizen, 1989; Berentsen et al., 1992b). The range used by Garner and Lack (1995) is 0.5 to 5 herds per week. The dissemination rate can be determined exogenously (as in most studies, including this) or endogenously, by the formula in Garner (1992).

Usually the dissemination rate decreases gradually as a result of transportation bans and increased awareness among farmers (Miller, 1979). Application of quarantines, movement restrictions, and producers' greater awareness slow the spread of the disease and are reflected in the model by a progressive reduction in the dissemination rate. These interventions are assumed to be imposed at different dates depending on the efficiency in diagnosing the first case and resource availability to enforce movement restrictions. It is highly unlikely, however, that the quarantines will be efficient enough to eliminate all dangerous contacts.

The dissemination rates for each half week period and each type of production unit are shown in Table B1. The estimated dissemination rates are significantly higher than those found in similar reports, reflecting the intensive production practices in the South Valley and the high density of susceptible animals. In order to evaluate the sensitivity of the simulations to these extremely high dissemination rates, a second set of runs was conducted with the highest dissemination rates found in the literature. ("Published rates.")

Table B1: Dissemination rates used in the simulations

Estimated rates					
week	large dairies	small dairies	feedlots	large pigs	backyard pigs
0	8	5	5	8	1
1-1	8	5	5	8	1
1-2	8	5	5	8	1
2-1	8	5	5	8	1
2-2	8	5	5	8	1
3-1	5	4	4	5	0.50
3-2	5	4	4	5	0.50
4-1	3	2	2	3	0.20
4-2	3	2	2	3	0.20
5-1	1	1	1	1	0.20
5-2	1	1	1	1	0.20
6-1	0.35	0.35	0.35	0.35	0.20
6-2	0.35	0.35	0.35	0.35	0.20
7th week and beyond	0.25	0.25	0.25	0.25	0.20
Published rates					
0	3	2.50	2.50	3	1
1-1	3	2.50	2.50	3	1
1-2	3	2.50	2.50	3	1
2-1	3	2.50	2.50	3	1
2-2	3	2.50	2.50	3	1
3-1	1.50	0.75	0.75	1.50	0.50
3-2	1.50	0.75	0.75	1.50	0.50
4-1	0.75	0.35	0.35	0.75	0.20
4-2	0.75	0.35	0.35	0.75	0.20
5-1	0.50	0.35	0.35	0.50	0.20
5-2	0.50	0.35	0.35	0.50	0.20
6-1	0.35	0.35	0.35	0.35	0.20
6-2	0.35	0.35	0.35	0.35	0.20
7th week and beyond	0.25	0.25	0.25	0.25	0.20

The transition matrix

Transition probabilities can be presented as a matrix. Each row shows the probability of being in any particular state in the next period when the system is presently in one specific state.

	Susceptible _{t+1}	Latent _{t+1}	Infectious _{t+1}	Immune _{t+1}	Depopulated _{t+1}
Susceptible _t	remaining susceptible	latent infection	0	effective vaccination	natural culling
Latent _t	0	incomplete contact slaughter	infectious	0	contact slaughter
Infectious _t	0	0	ineffective diagnosis	0	infected slaughter
Immune _t	decreased immunity	0	0	remaining immune	natural culling
Depopulated _t	restocking	0	0	0	remaining depopulated

Since all individuals have to be in one of the states in the next period, all rows add up to 1. The expected number of herds in each state in period $t+1$ is obtained as

$$E(x_{t+1}) = x_t A_t$$

where x_t is a row vector showing the number of individuals in each state in period t and A_t is the transition matrix. The path of the epidemic is simulated by repeating this exercise for several periods.

The most important transitions in this study are:

- *Susceptible to susceptible*: This probability is estimated as a remainder after the other probabilities have been calculated. It depends on the spread of the disease, the efficiency of vaccination (if it is used) and the speed of depopulation. Since this is the pool where new infections start, it represents the potential of the disease to continue for another period.
- *Susceptible to latent*: This depends on the number of effective contacts between infectious and susceptible herds in the previous period and the magnitude of the outbreak. This probability (p_{it}) in a particular period is a function of the fraction of infectious farms in the previous period (f_{it-1}) and the dissemination rate (dr)

$$p_{it} = 1 - \exp[-dr_{t-1} f_{it-1}]$$

- *Latent to infectious*: If they are not killed before, it is assumed that all herds become infected after being challenged. This transition depends also on the control policies, the availability of resources to promptly depopulate exposed premises, and the efficiency of diagnostic and depopulation programs. It takes the value 1 if only infected herds are depopulated, and the value 0 if all contact herds are also eliminated. It could take values in the range 0-1 reflecting different depopulation policies and efficiency of the programs.
- *Latent to depopulated*: This probability represents the slaughter of dangerous contacts. It depends on the control policy, the severity of the outbreak and the availability of resources for a speedy depopulation. Since depopulation of infected premises has the highest priority, dangerous contacts can only be killed if enough resources are available.
- *Infectious to depopulated*: This depends on the control policies and the efficiency in identifying and removing infected herds. If the diagnosis is efficient and there are enough resources to depopulate all infected herds in the same period, this transition is equal to 1; otherwise it is equal to the share of herds depopulated in the period.
- *Infectious to infectious*: If the authorities are less than 100% effective in identifying infected herds in the first period or if depopulation of infected herds cannot be accomplished in the same period they are diagnosed, some herds will remain infective in the following period. Two alternatives were considered: 5% and 10% of the infectious herds remain for at least a whole week. This transition is equal

to 1 minus the value of infected to depopulated.

- *Susceptible to immune*: If prophylactic vaccination is considered, this probability shows the efficiency of the vaccination campaign, which depends on the potency and adequacy of the vaccines, as well as the availability of trained personnel for vaccination. If vaccination is not considered, this transition is set to zero.
- *Depopulated to depopulated*: Any depopulated premise remains in that state until the quarantine is lifted. The value of this transition is 1.

Some of the transitions are set to zero because they are relatively small. Neglect of relatively unimportant characteristics of the process allows better identification of the main forces driving the simulation and generally yields more stable results. Some of the transitions that are set to zero in this model are:

- *Susceptible to culled*: This represents the probability that a non-exposed herd will be culled. The only possibility for a whole herd to be culled in normal times is that the farms ceases operations (a very unlikely option since most animals would probably be sold). It is assumed that during a FMD outbreak, no susceptible herds can be culled because of binding restrictions to the regional slaughter capacity.
- *Latent to latent, latent to susceptible and latent to immune*: All these transitions are zero because all latent herds become infectious in the next period, or are depopulated.
- *Susceptible to infectious*: This transition is zero because a premise can become infectious only if it was latent in the previous period.
- *Immune to susceptible*: This depends on the period of immunity and the control strategy (because it depends on whether the immunity comes from vaccination or recovery). Since the only policy is stamping-out or vaccination followed by depopulation of vaccinated animals, the animals in this category are not allowed to lose immunity.
- *Infectious to susceptible*: Infected cattle remain immune against homologous virus for at least three years. Since all infected animals are killed immediately after diagnosed, no infected animals become susceptible again.
- *Infectious to latent*: Same as above.
- *Immune to latent*: Even though herd immunity starts to decrease almost immediately after vaccination through births, it is assumed that the outbreak is controlled before the number of births is large enough to make a significant impact in the health status of the herd. Since healthy animals are not allowed into the quarantine area (except for direct slaughter), they cannot be challenged by the FMD virus.

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- *Depopulated to susceptible*: This is because depopulated premises cannot be repopulated until the quarantine is lifted.
- *Depopulated to latent*: Empty premises cannot become infected with the virus.
- *Depopulated to infectious*: Empty premises cannot become infectious.